COAXIAL TRANSMISSION LINE ELEMENTS

For Use in RF Amplifier
and Oscillator Tank Circuits

A Subsidiary of ⊞ **Alpha**

TTT Trans-Tech
"THE CERAMIC SOLUTION"

Introduction

For over 35 years, Trans-Tech, Inc. has been a leading producer of advanced technical ceramics. Modern manufacturing techniques and test facilities are utilized to ensure conformity to the most exacting requirements of commercial or MIL spec applications. Throughout the manufacturing process, samples are tested to assure performance consistency and high quality. With many years of experience, Trans-Tech has established extensive technical capability and practical knowledge which permits volume manufacturing while maintaining the commitment to excellence.

This brochure presents a description of Trans-Tech's Coaxial Transmission Line Elements which cover the broadest frequency range in the industry.

Trans-Tech, Inc.

A subsidiary of Alpha Industries, Inc., Trans-Tech, located in Adamstown, Maryland, is a leading manufacturer of advanced technical ceramics.

General

Trans-Tech introduces rugged ceramic coaxial line elements which exhibit higher circuit Q, superior parallel resonant impedance, and better temperature stability than classical inductor coils and associated inductor/capacitor lumped element components used in RF amplifier and oscillator tank circuits.

Typical Applications

DRO/VCO Oscillators
UHF (LC) Coupled Amplifiers
UHF Tuned Potential Amplifiers
Cellular Telephone
  - Mobile Radio
  - Portable Radio
  - Base Stations
Nationwide Pagers
Global Positioning System (GPS)
Tuned Oscillators
Narrow Band Filters
Duplexers
Wireless Communications

Features	Benefits
High Dielectric Constant	■ Circuit Miniaturization
Rugged Construction	■ Eliminate Microphonics
Tight τ_f Tolerance	■ Repeatability of Design
Long Term Stability	■ Negligible Aging Effects
Low Loss Silver Plating	■ Minimizes Environmental Effects on f_o
	■ Excellent Solderability
Acts as a Parallel Resonant Circuit or a High Quality Inductor	■ Improved Circuit Q
	■ High Resonant Impedance
SMT Configuration	■ Automation Compatible

Material Characteristics

	Material Type	
	8800	**9000**
Color	Tan	Dark Gray
Dielectric Constant	38.6 ± 2	90.5 ± 2
Temperature Coefficient of Resonant Frequency τ_f (ppm/°C) of TE_{01} mode	$+4 \pm 2$	$+6 \pm 5$
Q (1/tan δ) Min. of TE_{01} mode	>6000 @ 4.5 GHz	>1500 @ 3.0 GHz

Properties given for the ceramic materials used to produce the coaxial line elements are measured for internal quality control purposes. The electrical quality factor (Q) of the coaxial line elements is determined primarily by the metallization. Guaranteed properties of the coaxial line elements are listed on pages 3 & 4.

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Coaxial Resonators

Dimensions and Configurations

The Trans-Tech resonator components are available over a frequency use range of 310 to 4800MHz. Three mechanical profiles are offered to give the designer the greatest flexibility in selecting the electrical quality factor (Q). The high profile (HP) component has the highest Q but also has the largest size which may require special mounting considerations. The standard profile (SP) offers a compromise of electrical Q and mechanical size, and should be considered the component of choice for most applications. Where space is critical, the low profile (LP) component should be considered, but at the expense of some reduction in electrical Q.

These components are available in square configurations with outside dimensions of approximately .477" (12mm), .238" (6mm), and .156" (4mm). Length (ℓ) controls the operating frequency. Thick-film silver metallization is applied to form a Type Q ($\lambda/4$) or a Type H ($\lambda/2$) resonator. A Type Q resonator has all surfaces metallized except one end. For Type H resonators, surfaces are metallized except for both ends.
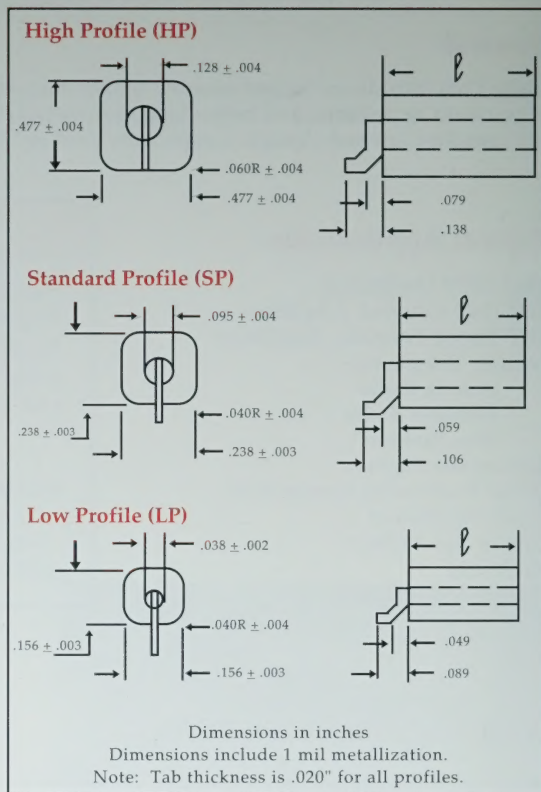

High Profile (HP)

Standard Profile (SP)

Low Profile (LP)

Dimensions in inches
Dimensions include 1 mil metallization.
Note: Tab thickness is .020" for all profiles.

Figure 1. Mechanical Configuration
of Resonator Components

Cylindrical configuration (CR) is non-standard but available on special request. Cylindrical configuration and material information presented in Trans-Tech publication #50080040 is obsolete.

Cut-Off Frequency

Cut-off frequency is a function of profile dimensions and dielectric constant. As the profile dimensions of the coaxial TEM mode components become comparable to the wavelength, higher order modes can be excited and effect device action. Figure 2 lists the cut-off frequency of the first higher order mode (H_{11}). The lowest cut-off frequency occurs for the largest profile (HP) and 9000 material.

Profile	Material Type	Cut-Off Freq. (MHz)
High Profile	8800	2120
	9000	1380
Standard Profile	8800	3735
	9000	2435
Low Profile	8800	6535
	9000	4250

Figure 2. Cut-off Frequency for the
First Higher Mode (H_{11})

Quality Factor (Q) Specification

The specified quality factors of the various resonator components offered are shown in Figure 3. The resonators are grouped by wavelength type ($\lambda/4$ & $\lambda/2$), material (8800 & 9000), and profile (HP, SP, LP). The listed Q value on each curve is the value guaranteed for the lowest operating frequency of each component type. The Q increases approximately as the square-root of increasing frequency. Typical Q's are 10% to 15% higher.
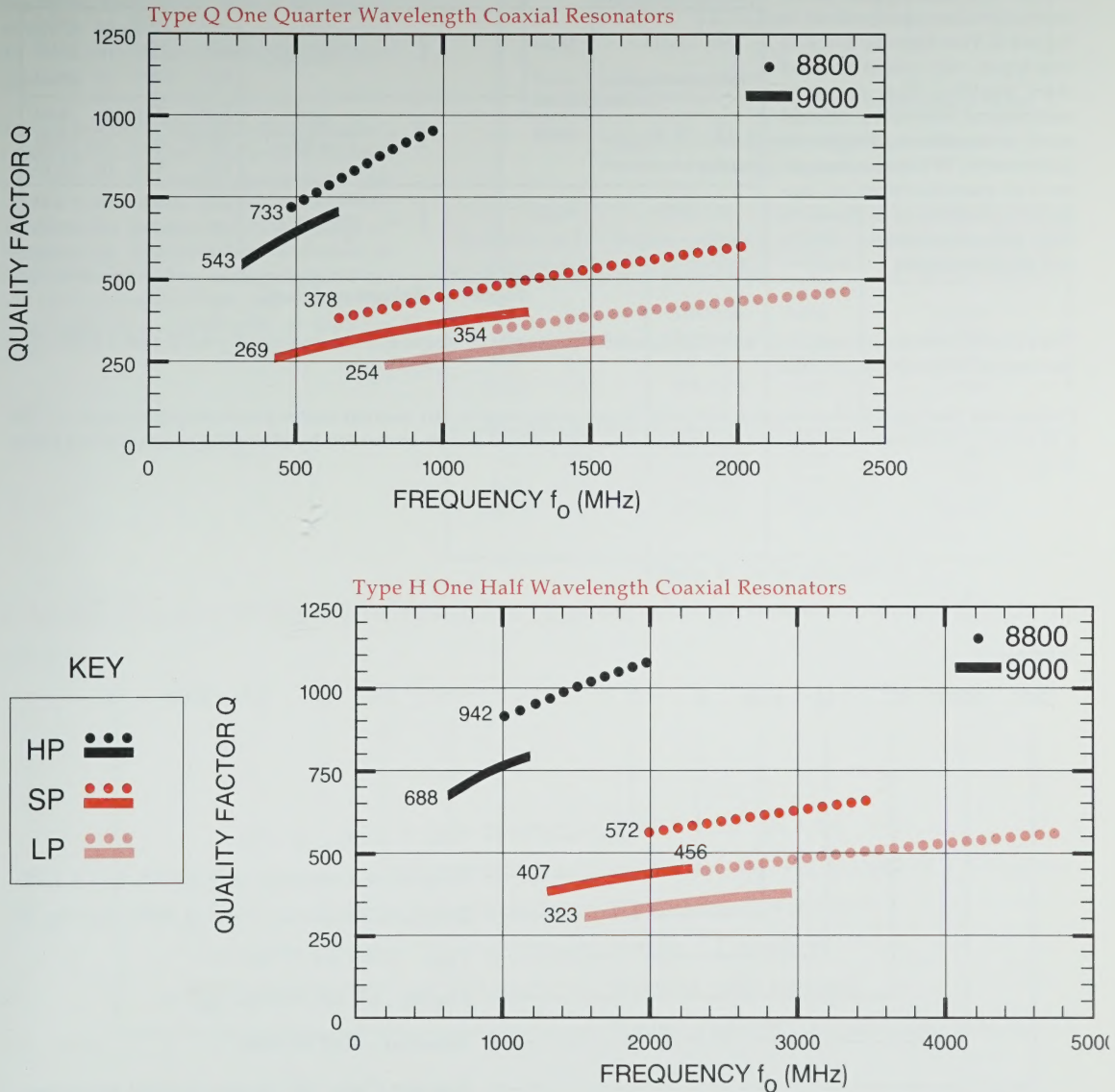
Type Q One Quarter Wavelength Coaxial Resonators

KEY

HP
SP
LP

Type H One Half Wavelength Coaxial Resonators

Figure 3. Quality Factor vs. Frequency

Standard Specifications

The various profiles, materials and types available for the Trans-Tech coaxial TEM mode resonators are summarized in Figure 4. You have a choice of two types, two materials and three profiles. This range of component variables should meet most circuit design requirements. While the component is manufactured to frequency, a formula is given so that the approximate length can be determined.

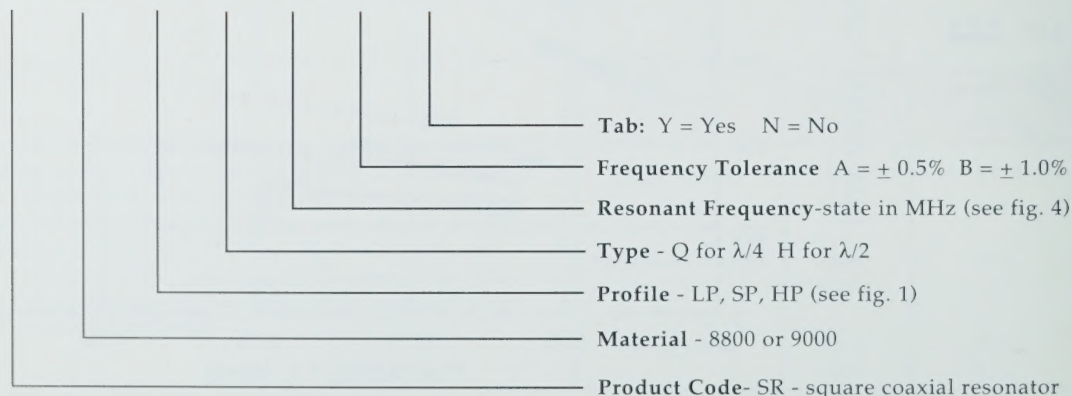| Type	Material	Nominal Length Formula (inches) ± .010"	Recommended Range f_0 (MHz)
Q (λ/4) quarter wavelength	8800	$\ell = \dfrac{475}{f_0 \text{ (MHz)}}$	HP 475 to 1000 SP 650 to 2000 LP 1200 to 2400
H (λ/2) half wavelength	8800	$\ell = \dfrac{951}{f_0 \text{ (MHz)}}$	HP 1000 to 1900 SP 2000 to 3500 LP 2400 to 4800
Q (λ/4) quarter wavelength	9000	$\ell = \dfrac{309}{f_0 \text{ (MHz)}}$	HP 310 to 650 SP 425 to 1300 LP 800 to 1550
H (λ/2) half wavelength	9000	$\ell = \dfrac{619}{f_0 \text{ (MHz)}}$	HP 650 to 1200 SP 1300 to 2300 LP 1550 to 3000

Figure 4. Selection Chart

The selected resonant frequency is available with two standard frequency tolerances of $\pm 0.5\%$ and $\pm 1.0\%$. The minimum tolerance is ± 2MHz.

Please note that your ordered value of f_0 will be set according to our measurement procedure (see page 6). The f_0 in your circuit may vary due to stray reactance. This offset can be corrected by changing your ordered value of f_0.

Coaxial Resonator Ordering Information

Example:

SR   8800   SP   Q   1300   B   Y

- **Tab:** Y = Yes   N = No
- **Frequency Tolerance** A = $\pm 0.5\%$ B = $\pm 1.0\%$
- **Resonant Frequency**-state in MHz (see fig. 4)
- **Type** - Q for λ/4 H for λ/2
- **Profile** - LP, SP, HP (see fig. 1)
- **Material** - 8800 or 9000
- **Product Code**- SR - square coaxial resonator

Note: See Solderability (page 7)

Dimensions and Configurations

Trans-Tech's coaxial inductors have been developed to meet the stringent demand of circuit designs where a high Q, temperature stabilized inductor is essential. **The recommended frequency range is from approximately one-half to two-thirds of self-resonant frequency.**

Listed below in Figure 6 are the inductance values offered. These components are similar to coaxial resonators, but have a nominal self-resonant frequency (SRF) and a precisely defined value of inductance. The standard inductor is square, low profile, and metallized on all surfaces except one end (Type Q). They may be ordered with or without tabs.

Low Profile (LP)

.038 ± .002
.040R ± .004
.156 ± .003
.156 ± .003
.049
.089

Note: Tab thickness is .020" for all profiles.
dimensions in inches
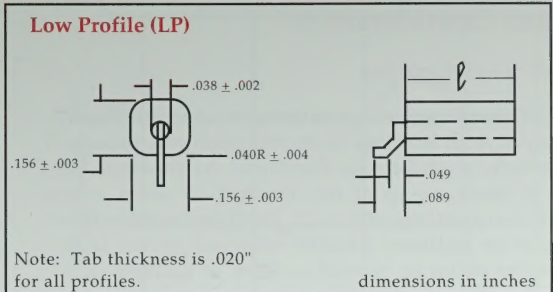
Figure 5. Mechanical Configuration of Inductor Components

Inductance L ± 5% (nanohenries)		Q Min/Typ	SRF (MHz)	Nominal Length (ℓ) (inches) ± .010"
	3.0	350/420	2065	0.230
@	3.5	340/400	1775	0.268
900	4.0	330/385	1550	0.307
MHz	4.5	315/370	1380	0.345
@	5.0	300/355	1240	0.383
800	5.5	290/340	1125	0.422
MHz	6.0	280/330	1035	0.460

Figure 6. Selection Chart

Coaxial Inductor Ordering Information

Example:

SI   8800   LP   Q   3.0   Y

Tab: Y = Yes   N = No
Inductance -(see Fig. 6) avail. in .1 increments
Class - Q for λ/4 standard
Profile - LP standard
Material - 8800 standard
Product Code- SI - square coaxial inductor

Note: See Solderability (page 7)

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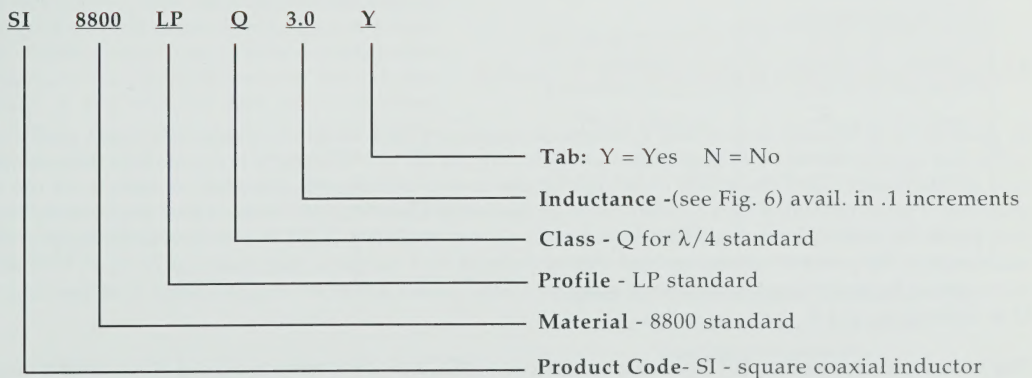
Other Considerations

Theory of Operation

At UHF frequencies, coaxial transmission lines manufactured with low loss dielectric mediums possess a number of useful circuit functions. As shown in Figure 7, when a coaxial line is short-circuited at the load, the input impedance (Z_{ss}) will perform the function of an ordinary parallel resonant circuit at frequencies equal to an odd number of quarter-wavelengths. If the coaxial line is open-circuited at the load, the input impedance (Z_{so}) will be very low at quarter-wavelength points and act as a parallel resonant circuit at the half-wavelength points. For a given operating frequency, the length (ℓ) of the coaxial line required to meet the above conditions will be inversely proportional to the square root of the dielectric constant of the coaxial line medium.

As shown in Figure 7, coaxial transmission lines can function as low-loss inductors or capacitors by employing the proper combination of length, frequency and termination. A short-circuit line will exhibit inductive reactance when less than one quarter wavelength long and a capacitance reactance when between one quarter and one half wavelength long. For an open-circuit line, the conditions for inductive and capacitive reactance are interchanged.

When using these coaxial components as inductors, the dielectric constant is not of major importance because the internal inductance of the coaxial component is independent of the dielectric medium.

Figure 7. Variation of Z_{ss} on short-circuit and of Z_{so} on open-circuit lines as a function of wavelength (λ)

Measurement Description of Q, f_0, and L

Evaluation of Q (quality factor) and f_0 (resonant frequency) of coaxial components is made with a one-port reflection measurement on an automatic network analyzer (ANA). The probe is moved into the inner diameter (ID) of the device until the input resistance of the device matches the terminal resistance of the network analyzer. This is indicated by a 50 ohm circle on the Smith Chart display and is known as "critical" coupling. The point on this circle where the response is purely resistive (capacitance reactance equals inductive reactance) is the point of resonance and will be defined by a complex impedance of Z=50 + j 0 ohms. The Q is computed by observing the frequency span between VSWR - 2.616 (Z=50 ± j50 ohms) on either side of f_0. The Q is defined as $f_0/\Delta f$.

The inductance parameter (L) is measured with an APC-7mm connector mounted flush with a conducting plane and full one-port calibration (open, short, broadband 50 ohm load) is performed. The inductor is then clamped into place with the tab touching the inner conductor and the metallized body touching the grounding plane. The inductance (L) is measured at the frequency indicated in Figure 6. The impedance vector on the Smith Chart of an ANA gives the necessary information where Z=R + j ω L.
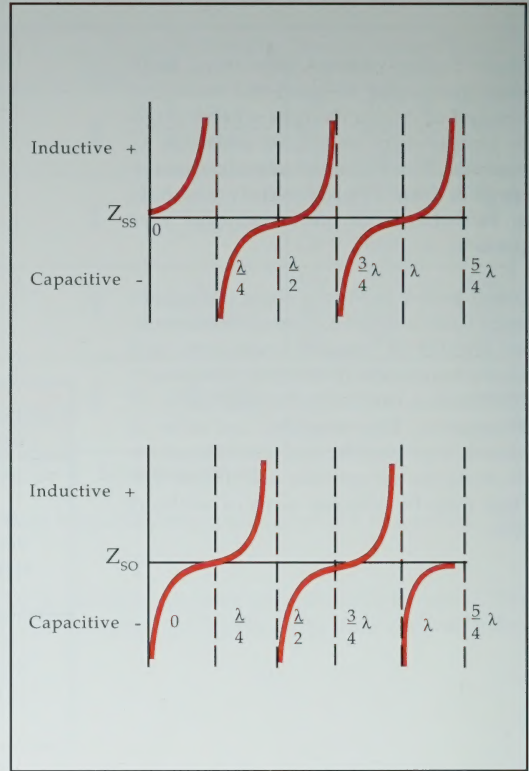
Solderability (to minimize leaching)

Trans-Tech's coaxial components in the SP and LP profiles are compatible with standard surface mount re-flow and wave soldering methods. The HP profile components may require mechanical support mounting because of the larger size. Consult the factory for details.

To minimize leaching, use silver-bearing solder such as SN62 (62Sn-36Pb-2Ag). Trans-Tech tabs are pre-tinned to improve solderability. Additional attaching methods include hot air gun, infra-red source, soldering iron, hot plate, vapor phase and others. The coaxial component body is a ceramic and subject to thermal shock if heated or cooled too rapidly. Figure 8 is the recommended soldering profile, not to exceed 230°C for a duration of about 10 seconds. Repeatable results can be best achieved with air cooling only, no quenching.

Figure 9 indicates the maximum tolerance of the component planarity with respect to the datum plane.
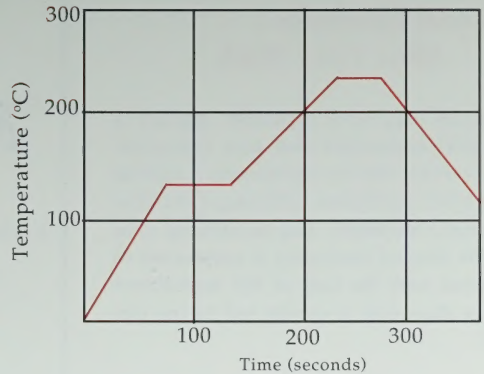
Figure 8. Soldering Profile
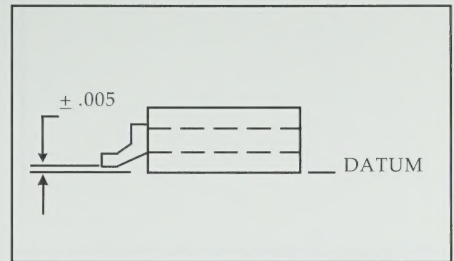
Figure 9. Surface Mount Tolerance
for Components with Tabs

Characteristic Impedance

As shown in Figure 10, the characteristic impedance (Z_0) of the coaxial TEM mode components is a function of the profile dimensions and the dielectric constant of the material. The 8800 material has a dielectric constant of 38.6 and the 9000 has a dielectric constant of 90.5. Z_0 is reduced over its air line value by the square root of the dielectric constant of the material. At one-eighth wavelength, the short-circuit line exhibits an inductive reactance while the open-circuit line exhibits a capacitive reactance equal in magnitude to Z_0.

	Characteristic Impedance	
Profile	8800	9000
High Profile	12.4 ohms	8.1 ohms
Standard Profile	8.5 ohms	5.5 ohms
Low Profile	13.0 ohms	8.5 ohms

Figure 10. Characteristic Impedance (Z_0)
for the Trans-Tech TEM mode
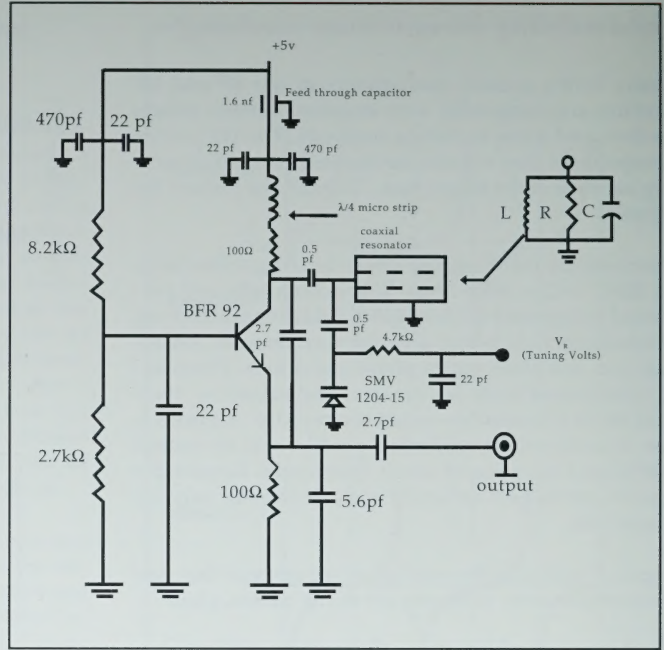coaxial components

Packaging

Tape and reel packaging is available. Consult the factory for details.

Coaxial Resonators and Inductors

Coaxial Elements - How They Work

Coaxial elements typically replace a parallel connected coil and capacitor. The circuit shown represents a typical 900 MHz oscillator utilizing a ceramic coaxial resonator. The metallized case of the coaxial resonator is connected to ground and the end of the metallized inner diameter is connected to the circuit.

High frequency transmission line theory can be used to derive several interesting properties of these coaxial components as given in the following three equations:

Equation [1] Circuit Q_c at f_o

$$Q_c = K \sqrt{f_o} \, (\ln D_r / d_r)(1/d_r + 1/D_r)^{-1}$$

where: D_r = outside diameter of coaxial resonator (inches)
   d_r = inside diameter of coaxial resonator (inches)
   f_o = desired resonant frequency (MHz)
   K = 240 for D8800 material
   K = 200 for D9000 material

An approximation of the unloaded Q can be calculated from equation 1. For the metallization and materials used by Trans-Tech, the magnitude of the constant (K) is 240 and 200 for the D8800 and D9000 materials respectively.

Equation [2] Input Impedance at f_o

$$Z = 4827 \sqrt{f_o} \, (n)^{-1} (\ln D_r / d_r)^2 (1/d_r + 1/D_r)^{-1} \text{ ohms}$$

where: n = 1 for $\lambda/4$ class resonators
   n = 2 for $\lambda/2$ class resonators

At parallel resonance, the impedance is purely resistive and given by equation 2.

Equation [3] Resonant Frequency

$$L = 2952.756n \, (f_o \sqrt{\varepsilon'})^{-1} \text{ inches}$$

where: ε' = dielectric constant of material

For a desired resonant frequency the length of the coaxial element is given by equation 3. Notice that only the desired frequency and material dielectric constant enter into this equation.

TRANS-TECH CAPABILITIES

Dielectric resonators ▶
for DRO/VCO and filter
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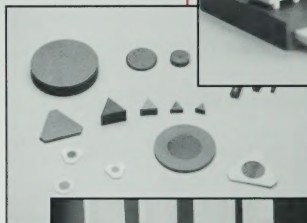
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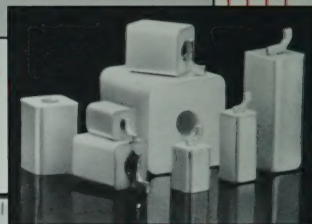
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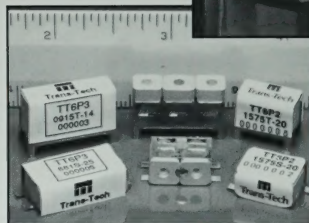
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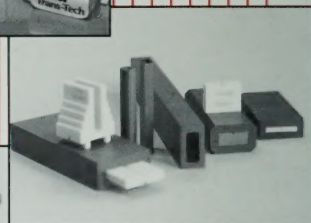
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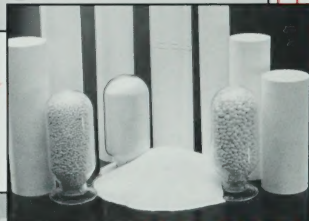
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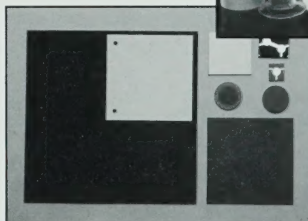
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